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1. Your reference	C1321.00/C
2. Patent application number *(The Patent Office will fill in this part)*	11 JUN 2003 0313470.7
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Cambridge Consultants Limited Science Park Milton Road Cambridge CB4 0DW
0036161800 4 Patents ADP number *(if you know it)*	
If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4. Title of the invention	Handwheel-Operated Device
5. Name of your agent *(if you have one)*	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Keith W Nash & Co 90-92 Regent Street Cambridge CB2 1DP
Patents ADP number *(if you know it)*	1206001
6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	a) Yes

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Continuation sheets of this form	
Description	13
Claim(s)	CF
Abstract	
Drawing(s)	6 only

10. If you are also filing any of the following, state how many against each item.

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Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Keith W Nash & Co Date 06.06.2003

Keith W Nash & Co

12. Name and daytime telephone number of person to contact in the United Kingdom — David L Roberts - 01223 355477

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C1321.00/C

TITLE: HANDWHEEL-OPERATED DEVICE

Field of the Invention

This invention relates to a handwheel-operated device and to a method of controlling a motor of a handwheel-operated device by sensing rotation of the handwheel and causing the motor to rotate a chuck in dependence upon the rotation of the handwheel.

Background to the Invention

Mechanical devices of the kind having a handwheel connected to a chuck through a gear train, so that rotation of the handwheel causes a corresponding rotation of the chuck are well known. Hand drills and hand whisks are examples of such devices. These handwheel-operated devices are popular because a handwheel affords a high degree of control over the speed of rotation of the chuck. However, the magnitude of the speed and/or torque that can be developed at the chuck is limited by the magnitude of the speed and/or torque applied to the handwheel, which must be provided by the user. Such devices are therefore unsuitable for use over long periods or by users who lack physical strength, or if high levels of both speed and torque are required.

Summary of the Invention

According to a first aspect of the invention there is provided a handwheel-operated device comprising a body, a handwheel causes aand a chuck, the handwheel and the chuck being rotatable relative to the body, the device further comprising a first motor operable to rotate the chuck, first sensor means responsive to rotation of the handwheel and first control means operable in conjunction with the first sensor means to cause the first motor to rotate the chuck in dependence upon an angular displacement and/or angular velocity of the handwheel.

The invention therefore provides a handwheel-operated device that is operable by a user in the same manner as a conventional handwheel-operated device, such as a hand drill or a

obtain high angular velocities of the chuck that would otherwise require speeds of rotation of the handwheel that would be difficult or impossible for the user to achieve or sustain.

Precise control of the angular displacement of the chuck is useful where the device is used, for example, as a screwdriver, and a user wishes to align a screwdriving bit in the chuck of the device with a slot in the head of a screw.

The first sensor means may advantageously comprise an angular displacement sensor such as a rotary encoder. Preferably the handwheel is attached to a shaft of the angular displacement sensor.

In a preferred embodiment of the invention, however, a first gear wheel is attached to the shaft of the angular displacement sensor, a second gear wheel is attached to the handwheel, and the first and second gear wheels are engageable with one another either directly or via one or more intermediate gears, so that each revolution of the second gear wheel causes the first gear wheel to rotate through more than 360°, preferably a plurality of revolutions.

In this way, an inexpensive low-resolution angular displacement sensor, which produces, say, eight pulses during one revolution of its shaft, can be used, because each revolution of the handwheel will cause several revolutions of the shaft of the angular displacement sensor, and therefore a multiple of eight pulses during a revolution of the handwheel. Thus, provided that the ratio of the diameters of the first and second gear wheels is sufficiently large. The performance of an expensive high-resolution angular displacement sensor can be obtained using an inexpensive low-resolution encoder.

The device may advantageously further comprise second sensor means operable to determine a torque developed by the first motor, torque feedback means coupled to the handwheel and second control means operable in conjunction with the second sensor means to cause the torque feedback means to oppose the rotation of the handwheel.

Preferably the device further comprises switch means engageable with the handle, such that the first control means is operable to cause the first motor to rotate the chuck only when the handle is in the extended position.

Alternatively, the device may include a further manual control (for example a trigger switch), manipulable to cause the first motor to rotate the chuck when the handle is in its folded condition.

Preferably the device is a power tool.

In one embodiment of the invention the device is a cordless electric drill.

In another embodiment of the invention the device is an electric food blender.

According to a second aspect of the invention there is provided a method of controlling a motor of a handwheel-operated device, the device having a body, a handwheel, a chuck and a motor, the handwheel being rotatable relative to the body and the motor being operable to rotate the chuck relative to the body, the method comprising sensing rotation of the handwheel and causing the motor to rotate the chuck in dependence upon the angular displacement or angular velocity of the handwheel.

The invention will now be described by way of illustrative example and with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a cordless drill in accordance with the first aspect of the invention;

Figure 2 is a schematic sectional view of the drill of Figure 1;

Figure 3 is a partial schematic sectional view of the drill of Figures 1 and 2 along the line A-A;

Figure 4 is a block diagram of a first control scheme for the drill of Figures 1 to 3;

Figure 5 is block diagram of a second control scheme;

rotated, the second motor is driven. The second gear wheel has a diameter that is between three and four times the diameter of the first wheel. For each revolution of the handwheel, therefore, the first gear wheel makes between three and four rotations, which increases the effective resolution of the second rotary encoder by between three and four times.

The handwheel 36 has a folding handle 38, which is shown in an extended position in Figures 1 and 2. The handle can be moved into a folded position, and is engageable with a microswitch (not shown) in the folded position, which microswitch disconnects the second rotary encoder from the first control means.

The first motor and gearbox are secured in the body by resilient mounts, which allow a small amount of torsional movement of the motor and gearbox relative to the body. The gearbox is formed with a radially outwardly projecting member 40. A piezoelectric crystal (not shown) is located to either side of the member 40 such that if torsional movement of the motor and gearbox relative to the body occurs, a force is exerted on one or other piezoelectric crystal.

The arrangement of the member 40 and the piezoelectric crystals is shown more clearly in Figure 3, in which the piezoelectric crystals are denoted by reference numerals 42 and 44. Figure 3 is a sectional view along the line A-A of Figure 2.

Figure 4 shows a first control scheme in which the speed of rotation of the handwheel is measured and a pulse width modulated (PWM) voltage of magnitude proportional to the speed of rotation of the handwheel is applied to the first motor. As the handwheel is rotated, pulses are generated by the second rotary encoder. A first clock 46 determines the frequency of the pulses and generates a signal representative of the speed of rotation of the handwheel. The signal representative of the speed of rotation of the handwheel is used to generate a PWM voltage which drives a first field effect transistor (FET) h-bridge 48. The first motor 26 is connected across the first h-bridge 48.

In the control scheme of Figure 7 the handwheel 14 is rotated and causes the spindle of the second motor 32 to rotate and the second rotary encoder 56 to generate pulses. The first clock 46 measures the frequency of the pulses from the second rotary encoder and generates a signal representative of the speed of rotation of the handwheel. An amplifier 58 applies a gain to the signal representative of the speed of rotation of the handwheel to generate an amplified speed signal. The gain of the amplifier increases with the magnitude of signal representative of the speed of rotation of the handwheel. Figure 8 shows the gain characteristic 63 of the amplifier 58 with gain plotted against magnitude of the signal representative of the speed of rotation of the handwheel. Gain is plotted on the y-axis 65 and magnitude of the handwheel speed signal on the x-axis 67. The gain of the amplifier therefore determines the ratio of the speeds of rotation of the chuck and the handwheel. The amplified speed signal is applied to a first proportional plus integral (PI) controller 60.

The spindle of the first motor 26 rotates and causes the first rotary encoder 28 to generate pulses. A third clock 62 measures the frequency of the pulses and generates a signal representative of the speed of rotation of the first motor. The signal representative of the speed of rotation of the first motor is applied to the PI controller 60. A current sensor (not shown) measures the current flowing through the first motor and generates a signal representative of the current flowing through the first motor. The current sensor transmits the signal to the first PI controller 60. The first PI controller 60 generates a PWM voltage to drive the first h-bridge 48 to cause the spindle of the first motor to rotate at the speed determined by the gain of the first amplifier 58, whilst ensuring that the current flowing through the motor remains below a safe limit. The current limiting operation of the first PI controller 60 is explained in more detail below in relation to Figure 9. The battery 24, which was omitted from Figures 4 to 6 for the purpose of clarity, is shown in Figure 7 connected to the first h-bridge 48 and the second h-bridge 64 across which the second motor 32 is connected.

The piezoelectric crystal 42 and 44 generates a voltage proportional to the torque developed by the first motor 26. An attenuator 66 attenuates the voltage generated by the crystal 42 to generate a signal representative of a fraction of the torque developed by the

torque, rather than measured directly. The operation of the first motor 26, first rotary encoder 28, second motor 32, second rotary encoder 56, first clock 46, amplifier 58, first PI controller 60, first h-bridge 48, attenuator 66, second PI controller 68, current sensor 70, microprocessor 72 and third clock 62 is as previously described in relation to Figure 7. However, the first PI controller 60 receives the signals representative of the first motor current from voltage and current sensors 82 operable to generate signals representative of the voltage developed across, and current flowing in, the first motor 26.

The voltage and current sensors 82 transmit signals representative of the voltage developed across, and current flowing in, the first motor 26 to a second microprocessor 84. The second microprocessor also receives pulses from the first rotary encoder 28 and generates a signal representative of the load torque developed by the first motor 26, which is transmitted to the attenuator 66. The second microprocessor 84 implements a model of the motor, which is explained in greater detail below with reference to Figure 14. The attenuated torque signal is transmitted to the second PI controller 68 to cause the second motor 32 to generate a torque proportional to the load torque generated by the first motor, which torque opposes the rotation of the handwheel 14, as previously described.

Turning to Figure 14, this shows the model implemented by the second microprocessor 84. In the following description it is to be assumed that signals representative of a particular variable are signals representative of the Laplace transform of that variable. The second microprocessor receives a signal representative of the voltage applied to the first motor 26, and the current through it and a signal representative of the angular displacement of the rotor of the first motor from a reference orientation. From previous angular displacement signals the second microprocessor determines the actual speed of rotation of the rotor of the first motor. Using the model an estimate of the motor current and speed may be made. The estimated speed generates a signal representative of the back emf generated by the first motor. The back emf signal is substracted from the motor voltage signal to generate a signal representative of the estimated voltage across the windings of the first motor. The second microprocessor uses the estimated windings voltage signal to generate a signal representative motor current and of the total electrical torque generated by the first motor

K_{ω} - electric constant of the first motor; and

V_{bemf} - Laplace transform of the estimated back emf of the first motor.

Returning to Figures 11 and 12, the handwheel assembly of the drill of Figures 1 and 2 comprises the handwheel 14, folding handle 38, spindle 86 to which the handwheel is attached, circular thrust plate 88 through which the spindle 86 passes, and microswitch 90. The folding handle 38 is pivotally attached to the handwheel 14 and is formed with a cam 92. In the folded position (as shown in Figure 11) the cam does not engage with the thrust plate 88, which is biased towards the handwheel 14 by the microswitch. In the extended position, however, (as shown in Figure 12) the cam engages with the thrust plate 88, which causes the microswitch to be depressed, closing the microswitch. The second rotary encoder 56 is connected to the first clock 46 by the microswitch such that the handwheel is operable to control the rotation of the chuck only when the handle 38 is in the extended position and the microswitch closed. When the handle 38 is in the folded position (and therefore inoperable to control the rotation of the chuck, the rotation of the chuck may be controlled by the trigger switch 20, in the manner known from conventional cordless drills.

Figure 13 shows a hand whisk 94 in accordance with the first aspect of the invention. It will be appreciated that the electric hand whisk has two chucks (not shown in Figure 13), one for each whisking element 96 and 98. The hand whisk 94 has a handwheel and a handle 102. In this embodiment of the invention the handle 102 is not foldable, since the whisk can be disabled simply by unplugging it from the mains electricity outlet to which it is connected.

It will be apparent that the foregoing description relates only to six embodiments of the invention, and that the invention encompasses other embodiments as defined by the foregoing statements of the invention.

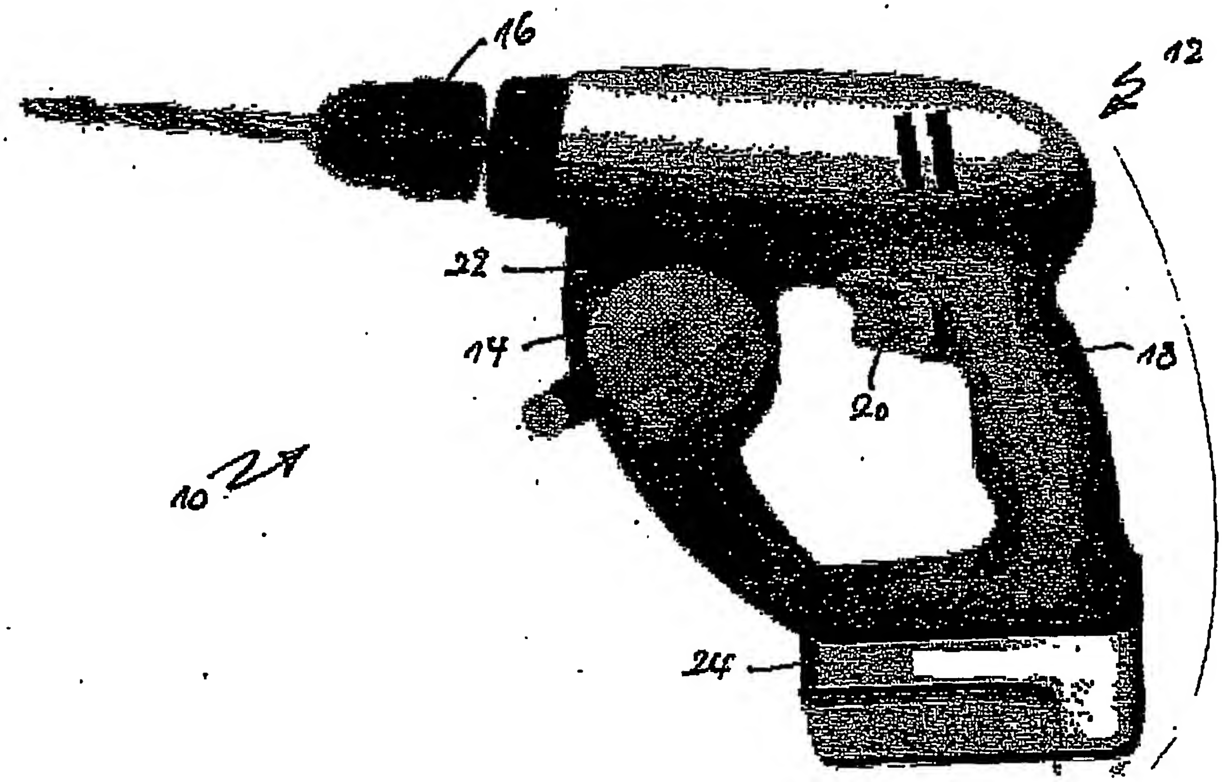

Fig. 1.

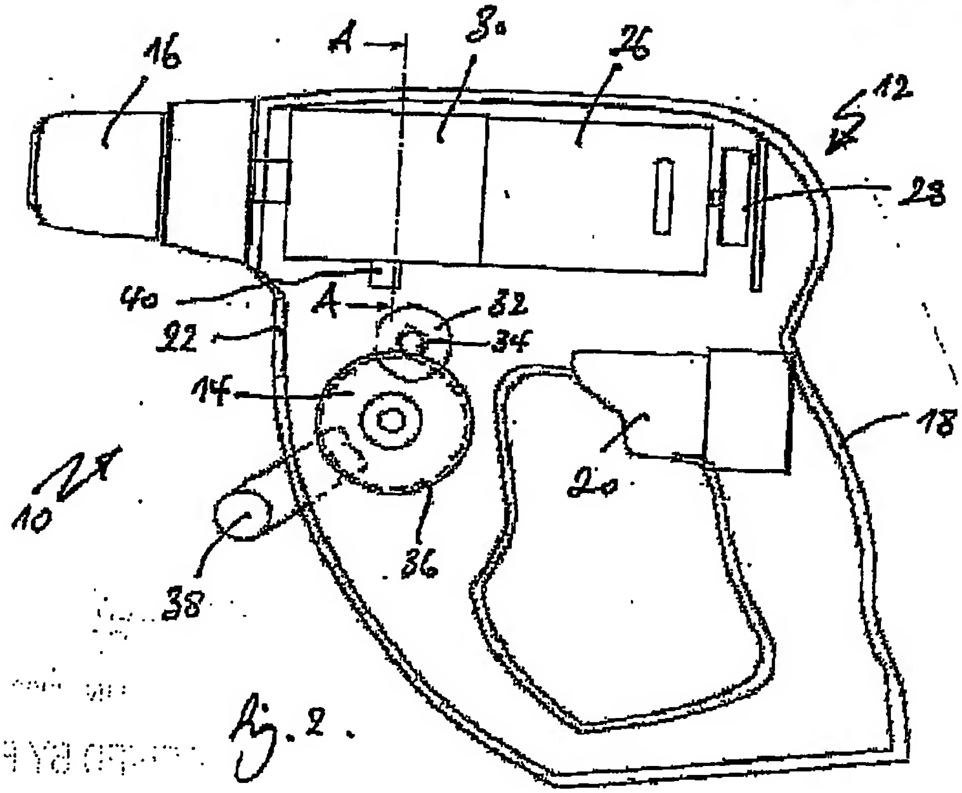

Fig. 2.

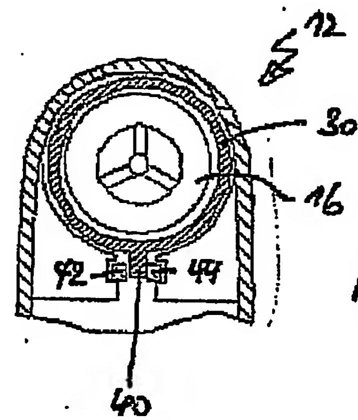

Fig. 3.

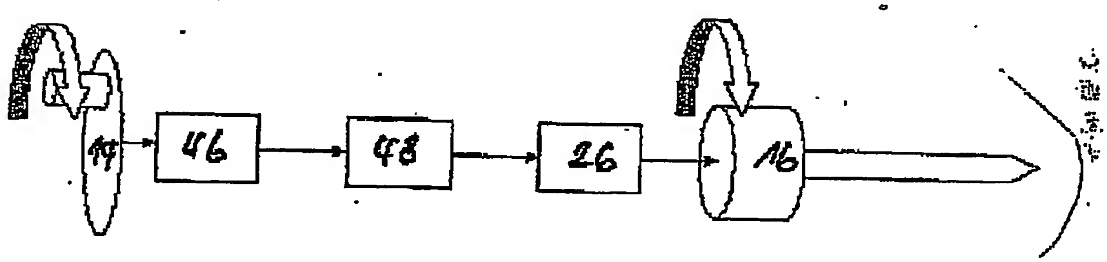

Fig. 4.

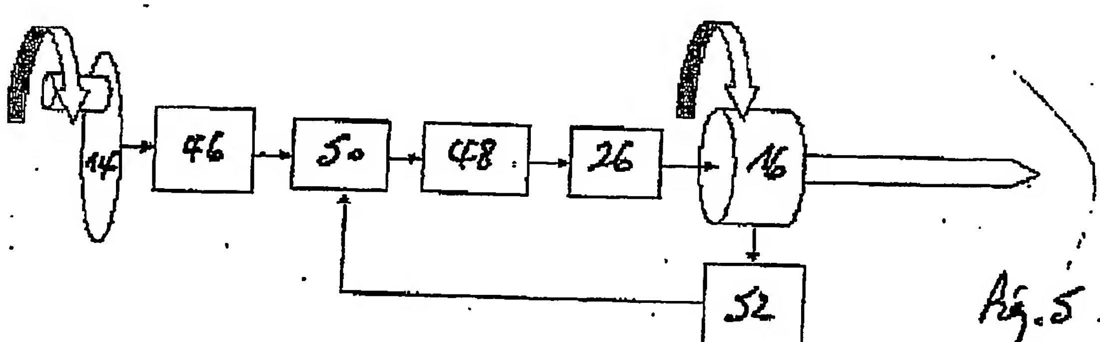

Fig. 5.

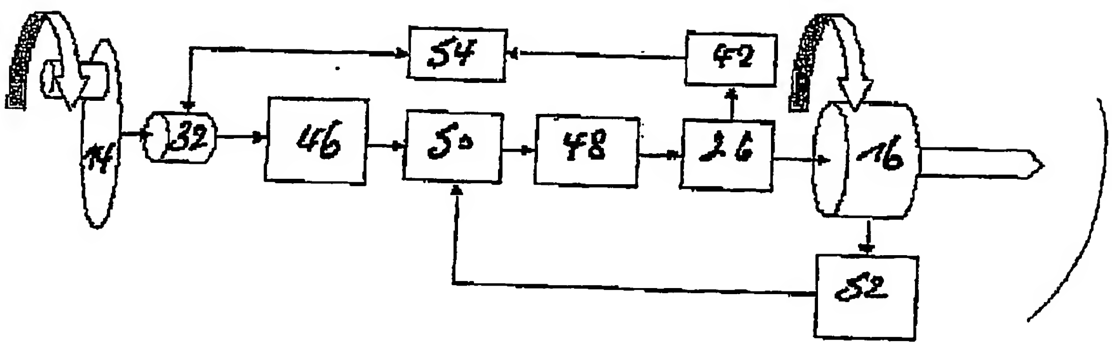
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Fig. 6.

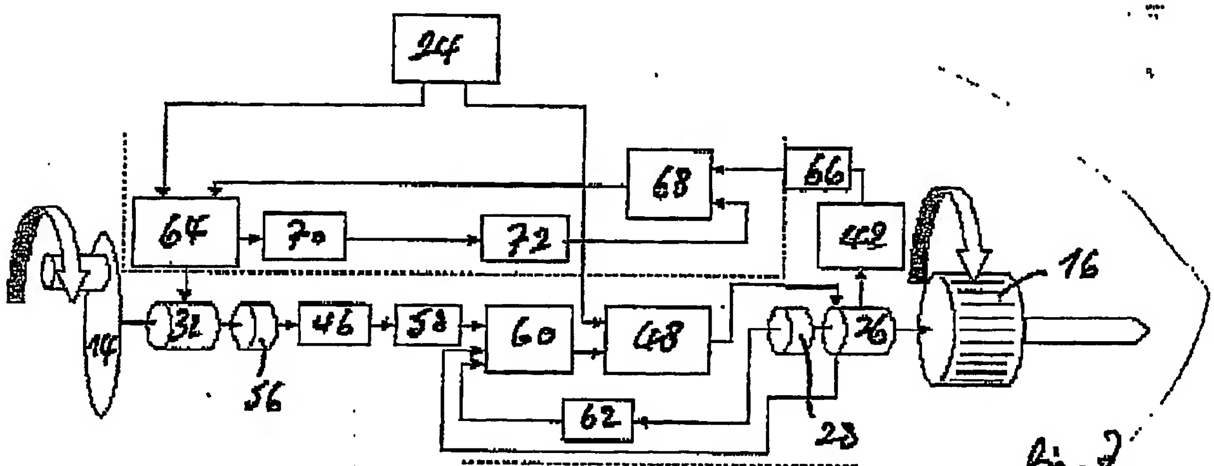
24
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Fig. 7.

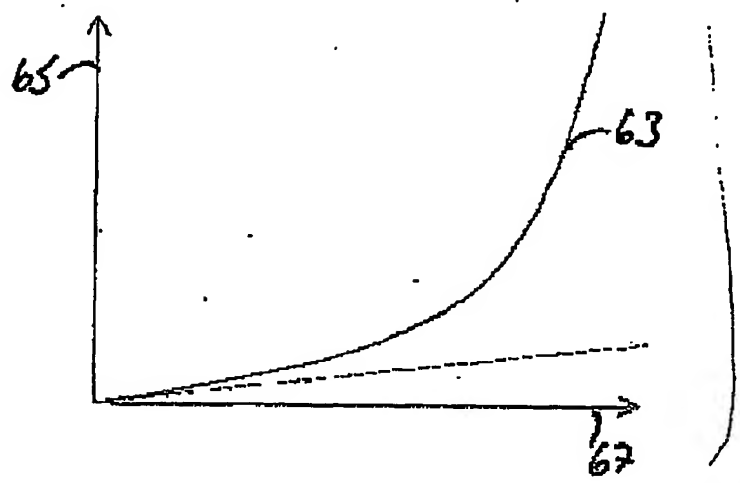


Fig. 8.

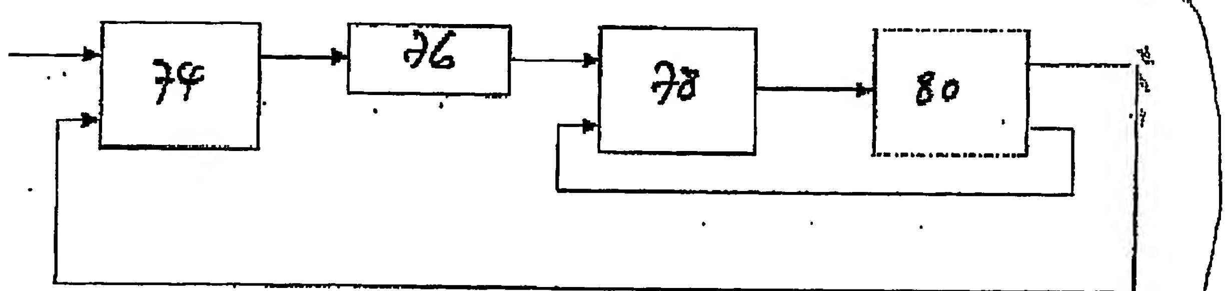


Fig. 9.

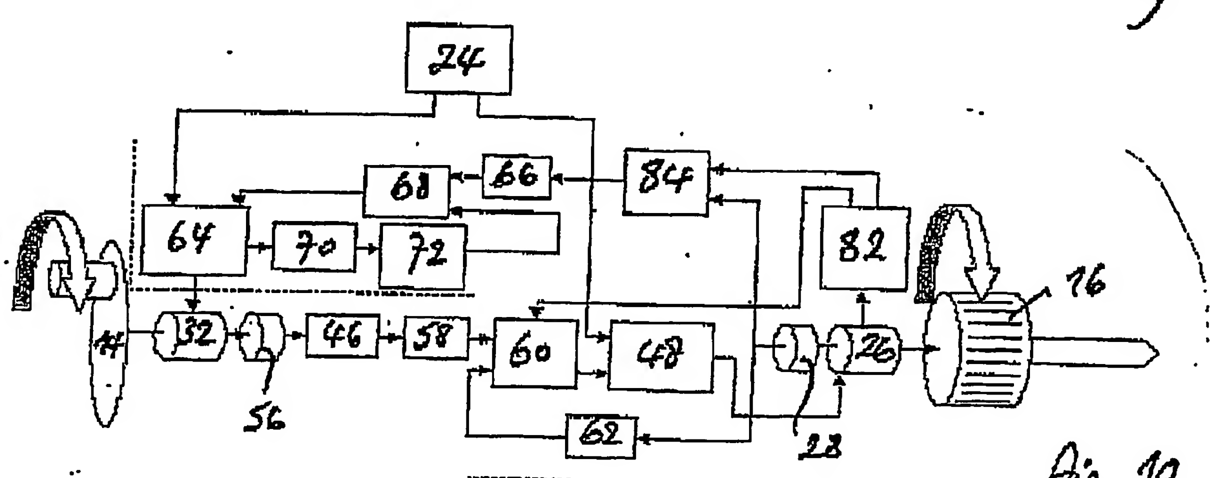


Fig. 10.

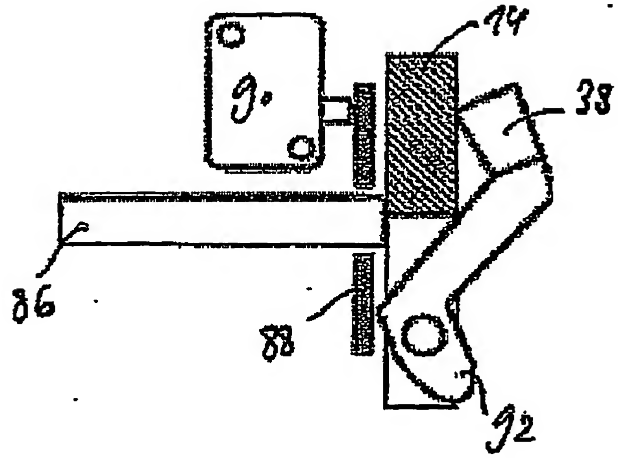


Fig. 11.

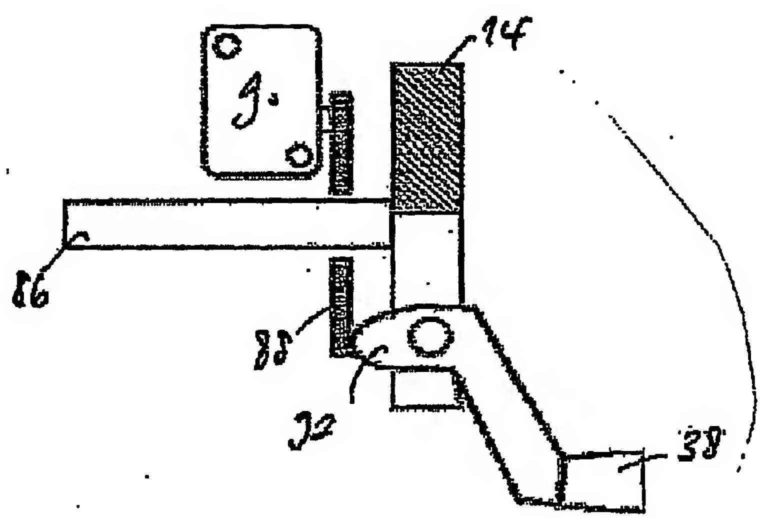


Fig. 12.

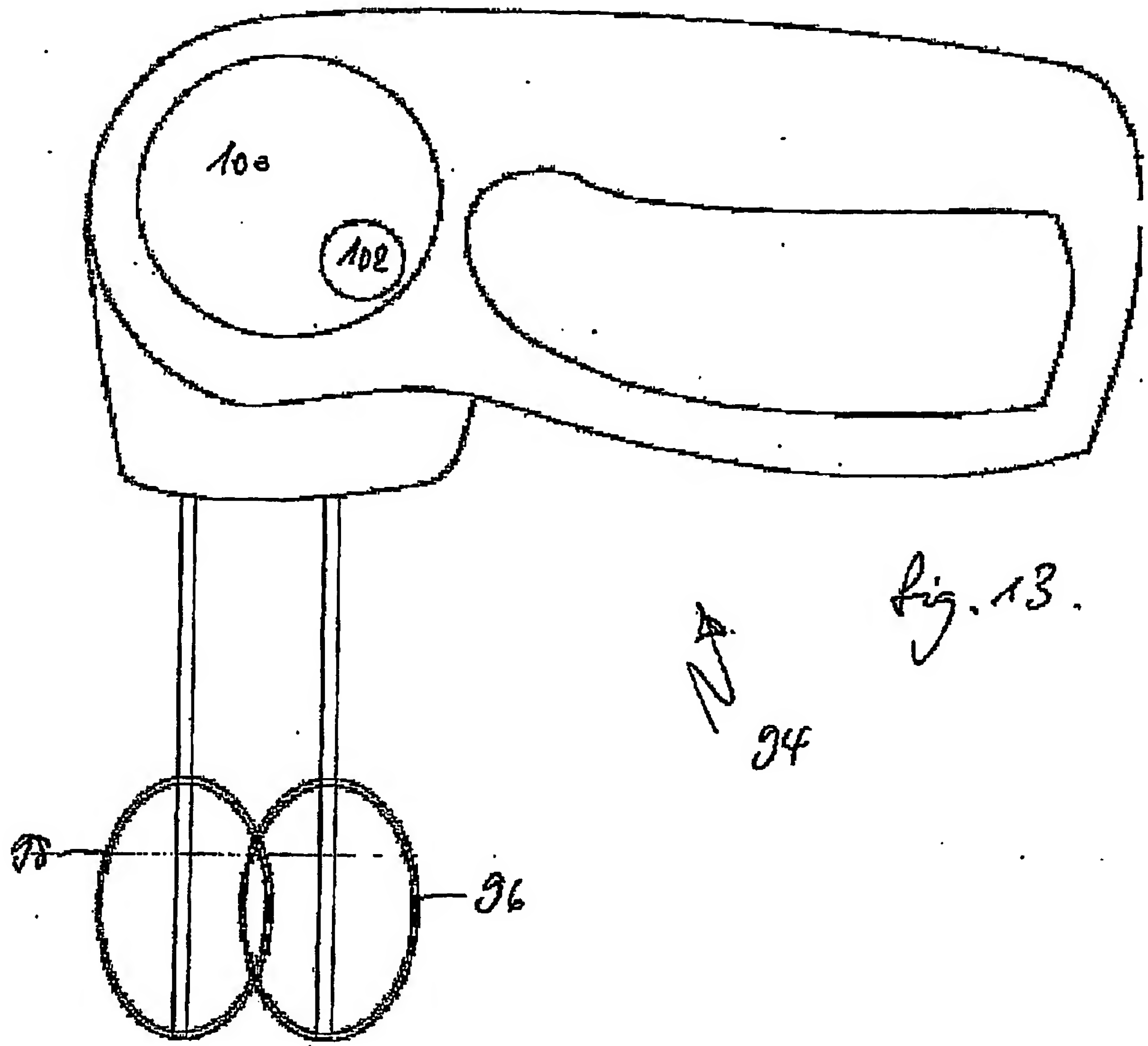
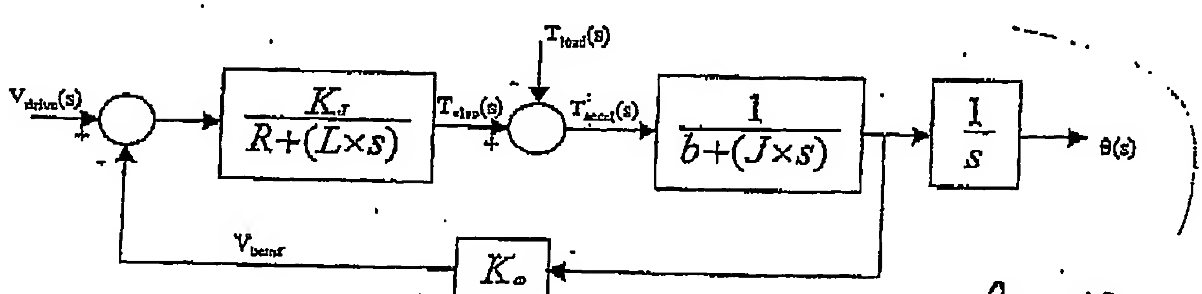

100
102
94
98
96

fig. 13.


$V_{drive}(s)$
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$T_{accel}(s)$
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V_{bemf}
K_ω

fig. 14.